Mapping Inundation at USGS Stream Gage Sites: A Proof of Concept Investigation

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Background

The USGS National Water Information System (NWIS) provides real time access to stream gage observations of river stage and discharge at over 7,000 locations nationwide. During periods of potential or actual flooding, NWIS provides invaluable information to hydrologists, emergency managers, local government, business, industry, farmers, and the general public. Stage and discharge are available in tabular form or plotted as hydrographs to illustrate current variations in flow compared with historical median values. Such data products are used to track the evolution of rapidly evolving river conditions that pose a threat to lives, property, and infrastructure.

Thanks to the availability of *The National Map's* digital elevation, orthoimagery, and vector feature data, USGS can potentially add significant value to NWIS offerings by providing geospatial information products to accompany tabular and graphical summaries. Inundation patterns, based on the combined use of streamflow and elevation data, could be displayed over orthoimages or vector features (transportation, hydrography, administrative boundaries, etc) to permit visualization of high water conditions in the vicinity of a stream gage. Map products of this kind would more clearly illustrate the consequences of high flows to a broad audience of users.

Furthermore, the National Weather Service produces river forecasts at 3,600 of the more than 7,000 USGS real time reporting gage sites. Inundation maps referenced to specific intervals of gage height and discharge can be used to illustrate impacts of forecast flows for warning generation purposes. NOAA recently commissioned a study of proposed methods and standards for producing flood severity inundation maps (Watershed Concepts, 2006), which called for the adoption of mapping standards developed for Digital Flood Insurance Rate Maps (DFIRMs) under FEMA's National Flood Insurance Program. We believe that USGS is well positioned to articulate a more comprehensive set of guidelines for inundation mapping **-** to address historical, current, and forecast flows in a variety of landscape settings, while drawing upon a range of elevation data sources, not the least of which are those of *The National Map*.

Hypothesis

We propose to engage expertise in the Water and Geography disciplines to test the following hypothesis, that:

USGS geospatial data resources can be effectively used to produce inundation maps illustrating flood extents and impacts at the 7,000+ USGS stream gages reporting in real time over the worldwide web, within defined and acceptable margins of uncertainty for a variety of urban and rural landscape settings.

Flood Mapping Approach

In an ideal setting, remote sensing imagery with observations of all historical streamflow events would be available from archives to allow inundation extents to be mapped given a forecast flow. There is incomplete image coverage of historical flow conditions in satellite imagery archives because of historical gaps in the satellite image coverage, resolution issues for smaller streams and rivers, and problems of cloud cover which often obscures rivers during major flood events. Even if such an archive were available, it would still not be possible to map inundation extents associated with flows in excess of historical flows. Other practical obstacles such as delays in receiving imagery of an ongoing event and cost of image acquisition make reliance on real time observation of inundation extents through remote sensing an impracticable approach for implementing a national operational flood mapping system. In spite of these limitations, satellite observations of inundation extents are useful for verifying other inundation mapping approaches where they are available (for example, Bates, 2004).

Flow simulation models coupled with digital elevation data are consequently the preferred approach for mapping inundation associated with the range of flow scenarios required for flood mapping and warning generation. Real time hydrodynamic modeling with two-dimensional (2-D), unsteady state flow models has been successfully demonstrated by the Washington Water Science Center (Jones et al., 2002). Two-dimensional models are particularly useful for representing the passage of a flood wave in the presence of obstructions such as urban infrastructure, in very flat terrain such as coastal areas and other complex topographic settings. However, these models require very high quality elevation data, considerably specialized expertise, computational power and expense in model set up, calibration and operation. These practical considerations limit their use to certain settings where high population density, the presence of high value infrastructure or physical complexities justify implementation. 2-D hydrodynamic modeling is also useful for evaluating the accuracy of simpler modeling approaches.

One dimensional (1-D) unsteady and steady-state hydraulic models, such as HEC RAS, coupled with GIS-based interpolation models for expressing model results in two-dimensions on the landscape also enjoy widespread use, especially for production of Digital Flood Insurance Rate Maps (DFIRM) (Tate et al., 2002; FEMA, 2002; Noman et al., 2001, EMRS, 1998; DHI, 1998). Even simpler approaches such as using uniform flow depths (obtained directly from gage readings or indirectly from flow simulations) have been shown to yield useful information about flood extents in the immediate vicinity of the gaging location. The degree of sophistication of hydraulic computations influences the magnitude of uncertainty associated with each of these modeling approaches in different topographic settings, and estimates of the associated uncertainty are required for accurate interpretation of the results (Pappenberger et al., 2005).

A variety of digital elevation data of varied resolution from multiple sources including high resolution LIDAR (3m), USGS NED at 1/3 arcsecond (10m), USGS NED at 1 arcsecond (30m), ASTER (30m) and SRTM (30m and 90m) are available within the National Atlas for characterizing topography. The use of any one of these digital elevation datasets in the preprocessing of channel characteristics and the postprocessing of inundation extents likewise results in flood maps of different accuracies (Asante et al, 2006). It would also impact the level of effort and the financial resources required to complete the implementation of a flood mapping system for all 7,000+ USGS gages. However, there is presently no definitive study that documents the accuracy of flood maps derived from data currently available through the USGS GIO in terms of surface area, flood stage and infrastructure impacted.

Integrated Hydrologic and Geographic Assessment

We propose a study that systematically varies the resolution of input elevation data and sophistication of hydraulic computations, to provide the basis for assessing the suitability of existing USGS datasets for mapping flood inundation at USGS gage sites. We will identify gaging sites with the following characteristics for evaluating methods for mapping inundation patterns associated with specified depth/discharge at a USGS gaging station:

1. Availability of a conventional 1-D model coupled with digital elevation data for interpolation of model results onto the landscape.
2. Availability of a 2-D hydrodynamic model for inundation mapping across a full range of stream flow scenarios
3. Availability of satellite or airborne remote sensing observations of inundated extent for a wide range of stream flow conditions
4. Availability of digital elevation data of varied resolution from multiple sources: high resolution LIDAR (3m); USGS NED at 1/3 arcsecond (10m); USGS NED at 1 arcsecond (30m); ASTER (30m); and SRTM (30m and 90m).

One such site is USGS station number 02084000 on the Tar River at Greenville, North Carolina, where RADARSAT synthetic aperture radar images for Hurricane Floyd flooding is available (Wang, 2002; Bates et al., 2006), as well as elevation data ranging from high resolution LIDAR to standard USGS DEMs. Additional stations situated in contrasting terrain (steep, flat) and land use will also be selected to represent a range of river valley conditions. Hydraulic models of varying complexity will be set up and coupled with digital elevation dataset of differing resolution to represent the range of complexity of inputs and processes. Flow events representing the historical range at the associated US gages will be routed through the hydraulic models to determine the resulting water surface elevations and to map the resulting inundation extent. The exercise will be repeated at USGS gaging sites located in different topographic and landscape settings. The results will be compared with the satellite observations. A matrix of outcomes will provide invaluable information on the gains made by increasing model complexity and elevation data resolution. This matrix will be the basis for guidelines on the suitability of joint use of specific data and computational methods for mapping floods in various terrain and land use environments.

Prior work by the North Carolina Water Science Center (Figure 1) has demonstrated that the integration of GIS preprocessing and postprocessing routines with hydraulic models, it is possible to create an *a priori* library of inundation maps, referenced to specific stage/discharge values at the USGS gages (Asante et al., 2005). The resulting flood mapping system allows flows currently observed at USGS gaging sites or flow/stage forecasts from the National Weather Service to be used expressed in terms of the spatial extent of flooding in near real-time. This allows for the generation of spatially specific flood warnings or the display of flood maps on the internet for end users to access. We will document the effort and cost associated with implementing such a system with various combinations of hydraulic methods and elevation datasets as appropriate. The analysis would allow us estimate the level of effort and funding required to complete implementation of a nationwide operational flood mapping system for all 7,000+ USGS gauges.

Expected Results/Products

1. A quantification of the relative accuracies of inundation mapping that are achievable with various combinations of elevation datasets and flood mapping approaches.
2. An understanding of the suitability of elevation datasets and flood mapping approaches for application in contrasting terrain and land use types.
3. An articulation of the cost, time and level of effort associated with completing inundation map libraries for all 7,000+ real time reporting USGS gage sites using various combinations of methods and datasets as appropriate.

4. Prototype automated GIS preprocessing and postprocessing algorithms for mapping inundation mapping at stream gage sites.
5. A manuscript reporting findings of this proof of concept demonstration, for submission to an appropriate, peer-review scientific journal.

Significance to the USGS Mission

We can add significant value to hydrologic observations at USGS stream gages by using our geospatial resources to illustrate flow conditions at these sites. GIO resources can significantly enhance flood hazard decision support to emergency managers, local government, business, industry, farmers, and the general public. Improved information of this kind will directly contribute to reduced loss of life and property to flooding disasters and better management of water resources.

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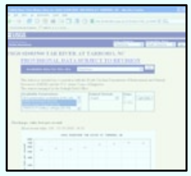
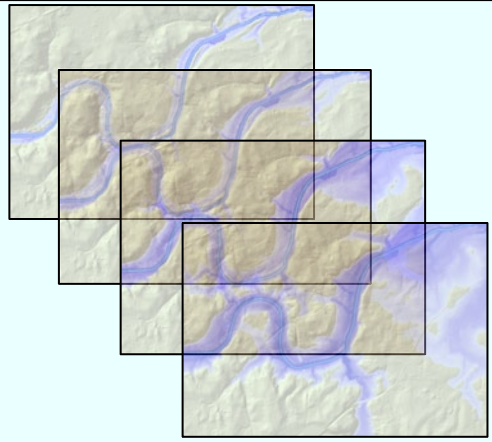
Figure 1. Inundation maps created *a priori* from digital elevation data, with reference to specified stage/discharge at a local gage site.

A flooding event on the Tar River, N.C.

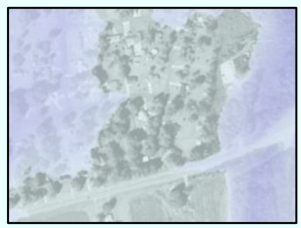


Real-time stream gages monitor the flood conditions

The USGS is collaborating with the National Weather Service (local forecast office, Southeast River Forecast Center, and the Hydrologic Services Division at headquarters) and with the NC Division of Emergency Management, Floodplain Mapping Program, to develop and implement useful real-time flood inundation maps and related information to emergency managers and the public. Utilizing an expanded network and rain, stream, and river stage gages in the Tar River Basin, the USGS is producing maps that show extent of inundation as a flood is occurring, depth of inundation, and key features such as roads, bridges, and public facilities. The maps are produced by using hydraulic models and detailed topographic data. Maps are linked to USGS real-time river stage gages so that as the river stage changes, the appropriate inundation map is displayed on the Web. This partnership among the USGS, North Carolina agencies, and the NWS is producing new capabilities that can be implemented throughout North Carolina and the nation and is providing North Carolina emergency managers with unique flood information for operational activities.



The appropriate flood inundation map is accessed from the library of images as flood conditions occur.



A web interface displays orthophotography, or other base layers, with flood inundation maps to view extent of flood and areas that may no longer be accessible by roadways

Project Support

Cooperators/Collaborators

At USGS Center for Earth Resources Observation and Science, Sioux Falls, SD:

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Other Project Support:

At USGS Center for Earth Resources Observation and Science, Sioux Falls, SD:

Related studies
Flood Hazard Characterization in Africa, USAID and UNEP - $100,000 anticipated
Kabul Flood Hazard Mapping, USAID/Afghanistan- $50,000 anticipated
Mahanadi Inundation Mapping, USAID/India - $25,000 anticipated

At North Carolina Water Science Center, Raleigh, NC:

Related studies
Real-time floodplain inundation mapping for the Tar River, North Carolina - $132,000
Two-dimensional flood routing, Neuse River, North Carolina - $150,000 anticipated
Mahanadi Inundation Mapping, USAID/India - $50,000
Sutlej River Flash Flood Forecasting, USAID/India - $25,000

Budget Request

FY2007 Budget Request		
	EROS	NCWSC
	8836	2510
Personnel salary	$ 55,500	$ 55,500
Other expenses	$ 7,000	$ 7,000
Total Direct Costs	$ 62,500	$ 62,500
Cost Center Assessment	20%	20%
Indirect Costs	$ 12,500	$ 12,500
Total	$ 75,000	$ 75,000